

MICHIGAN STRUCTURE INSPECTION MANUAL

BRIDGE INSPECTION

CHAPTER 7

FRACTURE CRITICAL & FATIGUE SENSITIVE INSPECTION PROCEDURES

7.01 Purpose

The National Bridge Inspection Standards (NBIS) define a fracture critical member (FCM) as a steel member in tension, or with a tension element, whose failure would probably cause a portion of or the entire bridge to collapse. The NBIS requires the identification of bridges that have one or more FCMs and the development of inspection procedures for each bridge due to the importance of monitoring components without structural redundancy. Michigan currently has over 160 bridges that contain fracture critical members, and over 85 percent were constructed prior to the enactment of specific fabrication guidelines and material testing for FCMs. The proper identification of FCMs and the implementation of inspection procedures are necessary to preserve such substantial transportation infrastructure assets.

The primary cause of FCM failures is fatigue. For this reason the inspection of FCMs requires a comprehensive knowledge of the AASHTO Fatigue Categories. There are also redundant structures that have details that are low in fatigue resistance and are prone to cracking. Although NBIS does not require a separate inspection report for recording the condition of fatigue prone details, MDOT has developed the Fatigue Sensitive Inspection Report (FSIR) to be used for monitoring elements of these redundant structures. The procedures herein will assist inspectors to ensure a safe and functional highway system that will facilitate enhanced economic performance and quality of life.

7.02 Design and Fabrication Requirements

The implementation of fracture critical elements may only occur when geometric or structural constraints prevent the use of a bridge design with redundancy. The AASHTO *LRFD Bridge Design Specifications* and AASHTO/AWS-D1.5 *Bridge Welding Code* (BWC) require the use of stringent testing requirements and increased frequencies throughout the fabrication process. The AASHTO specifications also restrict designers from using details that are susceptible to fatigue induced cracking. Increased steel toughness requirements for many FCMs have resulted in the selection of high performance steels causing further escalation of capital costs during the construction phase.

The *Michigan Bridge Design Manual* requires that nominal fatigue resistance is calculated according to a 75 year design life, and that steel and fabrication procedures conform to the requirements of 12SP707(B) Special Provision for Fracture Critical Members. The special provision includes additional requirements for inclusion in the BWC Clause 12 Fracture Control Plan (FCP) for Nonredundant Members. The FCP requirement was initiated in 1978 as a means to guarantee that higher quality structural steel and fabrication testing is performed for all FCMs. As a result of this bridge designers are required to clearly identify FCMs on the plans for project bidding and fabrication requirements. Due to increased costs throughout fabrication, construction, and afterward through in-service safety

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inspections, all non-redundant steel or fracture critical designs must be approved by the Engineer of Development.

7.03 Fatigue Sensitive Details

Fatigue cracking occurs due to stresses from numerous live load cycles that cause failure below a material's yield stress. The factors directly associated with the initiation and propagation of brittle or ductile fatigue cracks are related to the amount of cycles, stress range, and fatigue category. AASHTO defines the number of cycles a bridge experiences for each truck crossing according to parameters such as span length and member type that contribute to the amplification of vibrations. Stresses inherent from fabrication procedures such as welding or the dead load of the structure are deducted from the stresses caused by live loads to derive the stress range. The AASHTO Detail Categories provide a hierarchy of fatigue resistance for in-plane bending according to developed thresholds.

The fatigue sensitive details provided in Section 6.4.5 of the BIRM provide descriptions, threshold values, suspected crack initiation locations, illustrative examples, and the assigned category. The categories are assigned in order of decreasing fatigue resistance. For example, category A has a threshold of 24 ksi compared to the lowest level 2.6 ksi for E'. Since fatigue prone details exist on both redundant and non-redundant structures the degree of inspection effort and urgency for repair will vary according to the location and type of structure. Areas that require significant attention during the inspection include the following locations:

- Details with section loss
- Triaxial constraint – members that cannot flex in any direction
- Field welds and welded attachments in the tension zone
- Intermittent welds
- Intersecting welds
- Welds perpendicular to the plane of stress
- Cover plates
- Out-of-plane bending
- Abrupt variations in cross section

7.04 Fatigue Sensitive Inspection Procedures

A separate Fatigue Sensitive Inspection (FSI) is currently performed on MDOT owned bridges which are redundant and have details with low fatigue resistance. Item 92D of the Structure Inventory and Appraisal Item (SI&A) form is coded Y to denote that a fatigue sensitive inspection has been completed. Two numerical digits are also included to denote the inspection frequency in months that is determined by the team leader. Where fatigue sensitive details exist on elements that are not fracture critical they are not required to be inspected at arms-length unless the initiation of a crack, corrosion, or other defect is suspected.

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7.04.01 Fatigue Sensitive Inspection Procedures – Bridge Owner Responsibilities

The bridge owner is responsible for ensuring that the bridge file is complete for each structure in their inventory. Plan sheets that provide the specific locations of the fatigue prone details are recommended to be in the file. If the inspection team leader submits a Request for Action (RFA) for the repair, evaluation, or other act involving a fatigue prone detail located on a structure with redundancy then it must be reviewed by the bridge owner in a timely fashion. The urgency shall be determined on a case-by-case basis but corrective action or a plan for additional monitoring must occur within 6 months from the observation.

The bridge owner is required to assign the FSI to the inspection team leader at least 30 days prior to the required inspection date. Although many fatigue sensitive details on redundant structures may be inspected from the ground with binoculars or other means, the bridge owner must assist the inspection team leader to facilitate an arms-length inspection when conditions warrant.

7.04.02 Fatigue Sensitive Inspection Procedures – Inspection Team Leader Responsibilities

The team leader must note the condition of the fatigue prone details and evaluate the areas of stress concentration around them for cracking, section loss, and out-of-plane distortion. The AASHTO fatigue details shall be closely examined as a guide throughout the inspection process. All cracks must be measured and quantified on the FSIR. RFAs must be submitted for structural evaluation or repair when section loss or distortion compromises the safe load capacity, or for any cracks discovered during the inspection. Fatigue prone details that exhibit section loss shall be closely examined and a detailed sketch prepared with measurements to monitor deterioration shall be placed in the file. Photos of all observed deficiencies shall be recorded.

Arrangements shall be made for inspection access equipment, or other necessary NDT testing instruments, on an as-needed basis following a FSI. These may include dye-penetrant testing kits, magnetic particle, or ultrasonic testing apparatuses. The inspection team leader should coordinate the scheduling of equipment and maintenance of traffic with the bridge owner. When a fatigue prone detail requires further inspection and represents a possible confined space, the inspection team leader must investigate to determine whether an entry permit is required and comply with all MIOSHA requirements. The team leader should review [BA-2014-01](#) prior to working in any railroad right-of-way.

Areas of noted deficiency on the FSIR shall be reviewed closely to determine whether a change in condition has occurred since the previous inspection. In instances where corrosion is exacerbating the service life of an element, the cause shall be referenced and maintenance procedures implemented to protect the element. These tasks shall be incorporated in the work recommendations for the bridge owner to review. The inspection team leader must enter the FSIR within 30 days of the field inspection.

7.05 Fatigue Sensitive Inspection Frequency

The inspections of fatigue prone details on bridges that are not fracture critical are considered as an optional special inspection. Thus, FSI inspections of redundant bridges may exceed a 24 month interval

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because the routine inspection is performed at a frequency that meets NBIS and MDOT guidelines. When conditions warrant an increased inspection frequency the inspection team leader is responsible for adjusting the interval according to engineering judgment.

7.06 Fracture Critical Structure Classification

Bridges with one or more FCMs are classified as fracture critical and Item 92A of the SI&A is coded Y to include the in-depth inspection. Two numerical digits are also included to denote the inspection frequency in months that is determined by the team leader. AASHTO and the FHWA provide similar classifications of fracture critical bridge superstructures. Since a FCM must be made of steel, or less often may be composed of aluminum, Items 43A and 44A must be coded as:

- Steel Simple Spans (Code 3)
- Steel Continuous Spans (Code 4)
- Aluminum (Code 9)

MDOT structure classifications for main and approach spans that often have FCMs are expressed as Items 43B and 44B which include the following:

- Girder and Floor Beam, Non-composite Deck (Code 03)
- Deck Truss (Code 09)
- Thru and Pony Truss (Code 10)
- Deck Arch with Filled Spandrel (Code 11)
- Thru Arch (Code 12)
- Suspension (Code 13)
- Stayed Girder (Code 14)
- Movable-Lift (Code 15)
- Movable-Bascule (Code 16)
- Movable-Swing (Code 17)
- Deck Arch with Open Spandrel (Code 24)
- Thru Girder (Code 25)
- Girder and Floor Beam, Composite Deck (Code 33)

Although the structure classifications comprise many of the fracture critical bridges in the inventory, other FCMs may exist that would not be identified through an audit of the structure classification. Examples of these include pin and hanger connections on three girder systems or a steel cross girder without load path redundancy (see Figure 7.01). FCMs identified by the inspection team should be reviewed by a knowledgeable engineer with experience in structural steel design. The appraisal should include an in-depth study to determine whether load path redundancy exists. Additional helpful information may be gathered by reviewing [NCHRP Synthesis 354](#). If the element is confirmed fracture critical the required field of SI&A Item 92A shall be updated to include a FCM inspection.

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Figure 7.01 Steel Cross Girder

7.07 FCM Inspection Procedures

Inspection team leaders are only allowed to assess the condition of FCMs through a detailed inspection. The NBIS requires FCMs to be inspected at arms-length which often requires the use of inspection equipment and traffic control that is not normally required during a routine safety inspection. Although the restriction of lanes has a negative mobility effect, the benefits of the inspection and providing a safe transportation system cannot be understated. Though individual local agency policies vary MDOT requires all FCMs to be maintained in Good or Fair condition.

7.07.01 FCM Inspection Procedures – Bridge Owner Responsibilities

The bridge owner is responsible for ensuring that the bridge file is complete for each structure in their inventory. Bridges with FCM's require additional detailed information to be included in the file. Plan sheets that delineate FCMs for both the superstructure and substructure components must be readily accessible. These drawings should be highlighted so the elements and FCMs may be readily identified by the inspection team leader and quality assurance review team. When a plan does not exist that includes designations for the FCMs the bridge owner must secure an engineer knowledgeable in structural steel design to provide a drawing for the file.

Fracture Critical Members that require immediate repair are considered a critical finding. In the event of an observed critical finding found by the inspection team leader the bridge owner shall respond immediately to facilitate the necessary appropriate actions to protect the public.

Although it is not required by the FHWA, the bridge owner or consultant is encouraged to employ staff that has successfully passed the FHWA-NHI-130078 *Fracture Critical Inspection Techniques for Steel Bridges* course.

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The bridge owner is required to assign the FCM inspection report to the inspection team leader at least 30 days prior to the required inspection date. Preparation for the fracture critical inspection should begin earlier to prevent delays when issues are anticipated to arise regarding traffic control or equipment scheduling. Failure to perform a FCM inspection on-time will result in the agency being held in noncompliance.

Although samples of each type of safety inspections are reviewed during the quality control (QC) process, the bridge owner shall review all Fracture Critical Inspection Reports (FCIR) for their inventory on an annual basis. This review should not necessarily be as detailed as a QC review, but must be performed to prioritize preventive maintenance repairs or schedule rehabilitation of fracture critical elements.

7.07.02 FCM Inspection Procedures – Inspection Team Leader Responsibilities

Once an inspection has been assigned the inspection team leader must review the bridge file to determine equipment and staffing needs. The locations of all fracture critical elements on the drawings are also to be reviewed and locations for accessibility will be considered. For MDOT owned bridges, the inspection team leader will notify the appropriate TSC personnel of the scheduled inspection and follow accepted department or region developed guidelines. The inspection team leader responsible for inspecting local agency bridges must coordinate the closure of lanes with the bridge owner so media releases or other measures may be completed.

Arrangements shall be made for inspection access equipment, or other necessary NDT testing instruments, on an as-needed basis prior to the inspection. These may include dye-penetrant testing kits, magnetic particle, or ultrasonic testing apparatuses. MDOT owns and operates reachall units that may be utilized by local agencies or a consultant acting on their behalf for FCM inspections. The inspection team leader is responsible for scheduling equipment, and ensuring that all required personal protective equipment is accounted for prior to the inspection. When an FCM represents a possible confined space, the inspection team leader must investigate to determine whether an entry permit is required and comply with all MIOSHA requirements. The team leader should review [BA-2014-01](#) prior to working in any railroad right-of-way.

The team leader must note the condition of the FCMs and evaluate the elements for cracking, section loss, and out-of-plane distortion. The AASHTO fatigue details shall be closely examined for cracks or distortion. All cracks will be measured and quantified on the FCIR. Areas with section loss shall be closely examined and a detailed sketch prepared with measurements to monitor deterioration shall be placed in the file. Photos of all observed deficiencies shall be recorded. RFAs must be submitted for structural evaluation or repair when section loss or distortion compromises the safe load capacity, or for any cracks discovered during the inspection. The presence of cracks in a FCM is serious, if not critical in many instances, and may constitute a critical finding that must be reported to FHWA. Follow the critical findings procedures outlined in Chapter 10.

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Areas of noted deficiency on the Fracture Critical Inspection Report (FCIR) shall be reviewed closely to determine whether the condition has declined, or if any actions must be taken. In instances where corrosion is exacerbating affecting the service life of an element, the cause shall be noted and maintenance procedures implemented to protect the element. These tasks shall be included in the work recommendations for the bridge owner to review.

The FCM inspection must be performed in accordance with the BIRM, MBE, and the inspection procedures provided FHWA-NHI-130078 participant workbook. The inspection team leader must enter the FCIR within 30 days of the field inspection.

7.08 Inspection Frequency

The NBIS requires the inspection of FCMs at intervals that do not exceed 24 months. When conditions warrant an increased inspection frequency the inspection team leader is responsible for adjusting the interval according to the MDOT [NBI Rating Guidelines](#) and engineering judgment. For instances where there is one observed condition that requires additional monitoring it is recommended that the FCIR report is regularly updated by the team leader who performed the previously scheduled inspection.

7.09 Entering the Inspection Report

The inspection team leader shall submit the FCIR or FSIR using the MiB^{RIDGE} web-based system. Once the inspector selects to add a new inspection report, all of the physical and condition information located in the header will automatically generate once it has been entered following the initial routine inspection (see Figure 7.02). If any of the fields are blank the team leader may correct the data but must notify the bridge owner. The FCIR is comprised of seven sections after the heading, five of which must be entered by the inspector. For this example the FCIR will be used as the process is similar for the FSIR.



STR 646	Information Summary and Current Status				B01-09042
	Facility M-25	Latitude / Longitude 43.596507 / -83.894725	MDOT Structure ID 09109042000B010	Structure Condition Fair Condition(5)	
	Feature SAGINAW RI & MECHELEN DR	Length / Width 854 / 67.59	Owner MDOT Region - C and T		
	Location IN BAY CITY	Built / Recon. / Paint / Ovly. 1958 / 2005 / 1993 / 2005	TSC Bay City(4B)	Operational Status A Open, no restriction(A)	
	Region / County Bay(4) / Bay(9)	Material / Design 3 Steel / 16 Movable-Bascule	Last NBI Inspection 12/04/2013 / 9C8V	Scour Evaluation 3 SC - Unstable	

Figure 7.02 Information Summary and Current Status

The Fracture Critical, Special Inspection section includes fields for inspector name, agency/company name, inspection frequency, and inspection date (see Figure 7.03). The inspector's name and agency/company name is automatically generated according to the username and login information entered. The inspector may modify the monthly inspection interval by changing the previously assigned value. Since the date of the inspection often varies from the date of entering the report the inspector must select the date of the inspection from the auto-populating calendar.

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FRACTURE CRITICAL, SPECIAL INSPECTION		BMTN-TEST - 26HE	
Inspector Name	Agency / Company Name	* Insp. Freq.	* Insp. Date
MDOT Bridge Inspector	MDOT Bridge Inspector	12	<input style="width: 80%;" type="text"/>

Figure 7.03 Fracture Critical, Special Inspection section

The Inspection Procedures field is provided for bridge specific procedures and instances where a unique comment is required to facilitate the inspection (see Figure 7.04). **All FCM inspections performed after October 31, 2014 must include bridge specific procedures for the inspection.** The following is an example of the content that may be included in the FCM inspection procedure section:

1. Review bridge file prior to the inspection for outstanding RFAs or significant correspondence.
2. Review the highlighted plan sheet(s) that denote FCM locations.
3. Review previous FCIR for previous areas of deterioration or elements on plan sheet that are not listed.
4. Identify recommended NDT testing locations and provide the suggested frequency.
5. Identify factors or characteristics that may impede the inspection.
6. Inspect elements listed in Fracture Critical Elements section.

The inspector may also include any relevant information relating to traffic control, access, or any other details that will aid future inspections that are not already encompassed in the report. The Fracture Critical Elements section is intended to provide the specific elements and location(s) that the inspector must observe for signs of deterioration.

* INSPECTION PROCEDURES	Prev. Comment
1. Review bridge file for outstanding RFAs or significant correspondence. 2. Review drawings with designated FCM. 3. Review elements listed on previous FCIR. 4. UT pins every 36 months. (Last test 5/12/2012) 5. Locked gate preventing access at Span 1. Contact DPW for access.	

Figure 7.04 Inspection Procedures section

The Span Configuration information can be reviewed in the MiB^{RIDGE} by clicking on the SI&A tab and will be identified on the printed report as a hard copy or to portable document format (see Figure 7.05). This area is intended to assist those reviewing the report to view the structure classification, quantity of spans, and the amount of lanes on the bridge without having to reference the SI&A report.

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SPAN CONFIGURATION			
Bridge Type	16 Movable- Bascule	Appr Span Type	03 Gir-Flr Bm Non Comp
Main Span	N	Appr Span	3 Steel
# of Main Spans	1	# of Appr Span	6
Lanes On	4	Lanes Under	2
47L-Left Horizontal Clear (ft)	0.0	47R-Right Horizontal Clear (ft)	39.7
54B-Left Underclearance (ft in)	0 ft. 0 in.	54D-Right Underclearance (ft in)	15 ft. 5 in.

Figure 7.05 Span Configuration section

The NBIS Ratings and Comments for the stringer (Item 59 Superstructure) and paint are automatically transferred from the BSIR in the fourth section on the printed report (see Figure 7.06). The rating and comments recorded during the routine inspection reflect the general overall condition of the superstructure for this element. The paint rating is also included as a means to increase awareness of the coating system protecting the FCMs.

NBIS RATINGS & COMMENTS (Latest Inspection Ratings Transferred from BSIR)		
Stringer (SIA-59):	7	Built up members are in good condition overall. Paint peeling in a few areas, some minor rust at beam ends. Pack rust forming between built up vertical stiffeners over piers. Some distorting of plates.
Paint (SIA-59A):	6	Paint is peeling in a few areas, good condition overall.

Figure 7.06 NBIS Ratings & Comments

Three columns are included in the Fracture Critical Elements section that includes fields for the inspector to select the type of element, describe the location, and provide descriptive comments regarding the condition (see Figure 7.07). The fracture critical elements list box includes a choice of the following items:

- Tension Areas of Main Girder
- Floor Beam Connections
- Floor Beams Spaced Greater than 14 Feet
- Pin and Hangers
- Cables
- Truss Chords and Diagonals
- Steel Cross Girder
- Steel Column
- Tack Welds
- Electro Slag Welds
- Short Cover Plates
- Type 1 Gusset (see Figure 7.08)
- Type 2A Gusset (see Figure 7.09)

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- Type 3 Gusset
- Cantilever Seat
- Tie Girder
- Suspension Hanger
- Gusset Plate Truss
- Other

The location should identify the span with additional details provided so the element may be located during the next inspection. Ratings are to be assigned in the comments section as Good, Fair, Poor, Serious, and Critical according to the MDOT NBI Rating Guidelines. Any FCM that is rated Serious or Critical requires immediate bridge closure until repairs are performed. All FCIRs require a comment to be provided to describe the general condition of each element regardless of the rating.

FRACTURE CRITICAL ELEMENTS		
FC Element	Location	Comments
Tension Areas of Main Girder	Spans 2, 4, 5 & 6 Lower Flange, Span 3 Bascule Span	(10) - Good Condition - Spans 2, 4-6 have areas of light corrosion along the bottom flange. Span 3 (Bascule Span) has numerous areas of plated repairs over section loss. There are several repairs to the vertical web stiffeners where there was heavy section loss. Span 3 W Bascule N
Floor Beams (Spa > 14?)	Spans 2-6, Stringers are simply supported on FB's	(10) - Good, Light areas of corrosion along flanges and near connections.
Steel Cross Girder	at P1 and P6, supporting Spans 1 and Span 7.	(09) - Good Condition - There is a steel built up cross girder about P1 and P6. This girder is attached to the ends of the Main Girders for the adjacent spans. Note Bearings for Stringers on top of Cross Girder are tilted towards the river. Bearing 8S above cross girder at n6 has daylight between

Figure 7.07 Fracture Critical Elements section



Figure 7.08 Type 1 Gusset

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Figure 7.09 Type 2A Gusset

The Miscellaneous Field Notes section allows the team leader performing the fracture critical inspection to note observations concerning non-fracture critical members (see Figure 7.10). The inspector must also note traffic control, special equipment, or if photographs were taken below the text box. Most FCM inspections will require traffic control and equipment such as a bucket truck or reachall for an arms-length inspection. The comments field allows the inspector to provide additional details. The photographs radio button should only be selected no for an extenuating circumstance that must be noted in the section.

MISCELLANEOUS FIELD NOTES (Non-FC Members)			
Traffic Control:	<input type="text" value="Yes"/>	Comments:	<input type="text" value="Lane Closure"/>
Special Equipment:	<input type="text" value="4 Reach All"/>	Comments:	<input type="text"/>
Photographs?	<input type="text" value="Yes"/>		

Figure 7.10 Miscellaneous Field Notes section

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RECOMMENDATIONS & ACTION ITEMS (Click on Add to add Recommendations) [Add Recommendation](#)

* Recommendation Type	* Priority	Description
Steel Repairs ▼ Remove Recommendation	High ▼	Arrest crack in Span 2 FB3 originating at top of east connection bracket. Bridge owner contacted and RFA submitted.
Other-Superstr ▼ Remove Recommendation	Medium ▼	Replace leaking strip seal gland at P1.

Figure 7.11 Recommendations & Action Items section

The Recommendations and Action Items include three columns for recommendation type, priority, and description (see Figure 7.11). This section should not be construed as a replacement for the RFA form which is needed anytime action must occur prior to the next inspection. However, the information must be reviewed on annual basis by the bridge owner to prioritize maintenance and rehabilitation activities. The recommendation types include:

- Clean and Paint
- Steel Repairs
- Load Analysis
- Non-Destructive Testing
- Other – Superstructure
- Other – Substructure
- Other – Miscellaneous

The priority of high, medium, or low should be assigned for each recommendation and a description of the activity to be performed added. The description should include any pertinent information to assist the maintenance staff performing the repairs.

7.10 FCM Preservation

Preservation of FCMs is vital to ensure the long-term stability and safety of Michigan’s bridges. MDOT bridge staff clean all bascule bridges twice each year, and coordinates the pre-inspection cleaning with the Statewide Fracture Critical Bridge Inspector. Other bridges are cleaned on an as-needed basis according to environmental characteristics and recommendations provided by inspection staff. Potable water obtained from municipal sources in proximity to the locations is used by the statewide crews. The cleaning usually begins by concentrating on expansion joints to allow free expansion of the superstructure. All deck drains are flushed to allow for the proper drainage of precipitation from the deck so motorists are not adversely impacted by ponding water and to prevent accelerated corrosion of bridge elements. If the structure has open deck grating it is flushed from the top to remove any trapped dirt, debris, or material that may accelerate corrosion where it is connected to girders, floor beams, or

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stringers. All primary and secondary steel members are then cleaned utilizing the reachall to allow for the detection of cracks and section loss during inspection.

In instances where leaking deck joints, clogged drainage systems, or other matters indirectly affect a FCM, regional maintenance crews may be dispatched to resolve the issue. The bridge owner should review all work recommendations for FCMs on an annual basis for prioritization.

When a FCM requires repair for damage prior to the next scheduled inspection an RFA is generated by the team leader. Depending on the severity of the deterioration the bridge may require closure to prevent catastrophic failure of the structure. For MDOT owned bridges, the Emergency Bridge Coordination Engineer and Special Structures Unit are responsible for developing repair procedures that may be performed by the Statewide Bridge Crew or contract forces.

Due to the importance of preserving FCMs local agencies without maintenance crews should refer to a qualified consultant in order to implement a preventative maintenance program. It is recommended that local agencies implement a practice of cleaning fracture critical elements on a periodic basis if they have not already begun to do so.